AIAA 99-4446

LOW COST PLANETARY EXPLORATION VIA MICROMISSIONS

Steve Matousek[1]

AIAA 1999 Space Technology Conference and Exposition
Albuquerque, New Mexico
September 28-30, 1999

[1]Group Supervisor, Microspacecraft and Advanced Development Group, Mission and Systems Architecture Section, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, Senior member, AIAA

The work described was performed at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.

Abstract

Planetary exploration budgets and schedules continue to push the limits of affordability and feasibility. Micromissions are a way to revolutionize planetary exploration. Launching as a secondary payload on the Ariane 5 allows launch costs to be minimized. Current micromission allocations allow nearly 50% of the total mission cost to go to the payload. About one-third of the micromission dry mass is for the payload in probe delivery missions. These budget and mass fractions allow numerous opportunities for focused science and telecommunications/navigation relay missions for extremely low budgets. This paper examines the factors and technologies that make this revolution possible.

I. Ariane secondary history

Over twenty Earth orbiting micromissions in the range of 100 kg have been launched via the Ariane 4 secondary payload launch capability. These micromissions give considerable heritage to the concept of launching planetary micromissions via the Ariane 5. The first low Earth orbit secondary payload launch on Ariane 5 will occur around January, 2000 with the STRV1-c and STRV1-d payloads.

The Ariane 5 enables secondary launches to the planets because of the capability to launch two communications satellites at a time. This dual prime payload arrangement allows for management of the launch mass. Since the capability of the Ariane 5 must be large enough to launch two communications satellites, the majority of the time there is excess launch capability. Arianespace and CNES[2] plan to use this excess launch capability for Earth orbiting micromissions and for planetary micromissions in conjunction with NASA.

II. How do Micromissions get from GTO [3] to interplanetary space?

The Ariane 5 Structure for Auxiliary Payloads (ASAP5, see figure 1) allows single or dual slot launches of 100 - 220 kg. Planetary missions require the dual (or "twin") configuration due to ΔV requirements to escape the Earth. The launch takes place from Kourou, French Guiana. After the Ariane 5 upper stage delivers the primary communications satellite(s) to GTO, the ASAP5 micromission planetary payload is released.

Figure 1 shows the ASAP5 Qualification Model at Matra Marconi Space in Stevenage, England (photo courtesy of CNES, Arianespace, and Matra Marconi Space). The attached white objects are dummy test fixtures designed to simulate payloads.

After release from the ASAP5 structure and within a few days, the spacecraft does one or two ΔV burns near perigee. These burns place the spacecraft into a 10 - 60 day orbit with perigee still at about 250 km Earth altitude as shown in figure 2. This orbit allows proper phasing with the Moon and the correct geometry for the powered Earth flyby that sends the spacecraft on its way to the target. The multiple burn strategy developed by Paul Penzo gives up to a 6 month launch period, thereby increasing flexibility. Flexibility is important for a planetary secondary since it allows compatibil-

[2]Centre National D'Etudes Spatiales, the French national space agency

[3]Geosynchronous Transfer Orbit - ~250 km altitude at the closest point to the Earth and ~36,000 km at the furthest point from the Earth. This orbit is the intermediate orbit to the communications satellite geosynchronous orbit.

ity with the maximum number of communications satellite launches.

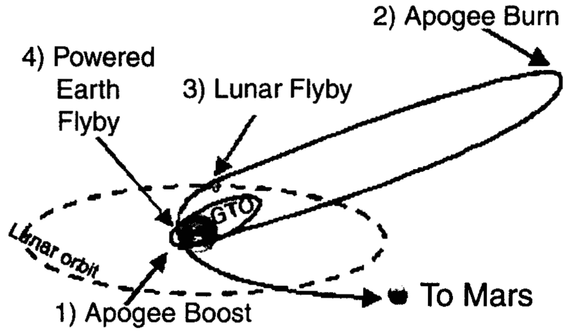

Figure 2 shows a simplified view of the 3 burn Earth-Moon system micromission trajectory. Not shown is the post-GTO series of orbits in the 1 to 5 day orbit-period range. This simplified view is not to scale. The lunar phasing orbit ranges in period from 10 to 60 days, depending upon launch date and time. For a 5 burn case, an additional lunar flyby (with additional required delta-V) is added to move the line of apsides towards the desired trans-Mars injection direction. For a 7 burn case, two additional lunar flybys (with additional required ΔV) are added above the 3 burn trajectory.

After the powered Earth flyby shown in Figure 2, the mission resembles a regular Mars mission. Cruise to Mars requires very few navigation maneuvers. The total ΔV required for a 2003 micromission probe delivery mission to Mars is 1650 m/s. The total ΔV for a 2003 Mars orbiter micromission is 2700 m/s. A 2005 micromission is more challenging due to the increased ΔV requirements. A 2005 micromission adds 300 m/s to the total ΔV of a 2003 probe delivery or orbiter missions.

These ΔV requirements for 2005 place a premium on mass and the efficiency of the propulsion system (see Table 1). The current maximum allowable ASAP5 launch mass is 222 kg. After subtracting 2 kg for the launch vehicle adapters, this yields 220 kg available for a micromission.

Table 1: ΔV Required for Future Mars Micromission Opportunities

Mars Opportunity	Probe Carrier ΔV (m/s)	Orbiter ΔV (m/s)
2003	1650	2700
2005	1950	3000
2007	1850	2700

III. Micromission Science and Enabling Technology

Many science investigations are possible via micromissions. The following classes of missions were identified in two workshops within the last year:

- penetrators
- flight within planetary atmospheres via balloons or aircraft
- small soft landers and/or rovers
- science orbiters

It is also noted that although not a science orbiter, a telecommunications/navigation orbiter can enable many missions whose payload does not have the resources to transmit data directly back to the Earth.

All of these science micromissions benefit from miniaturized sensors and short-range communications packages.

Penetrators
The New Millennium Program's Deep Space Two (DS-2) mission (see Figure 3)delivers two small probes to the surface of Mars via the Mars 98 lander. The probes impact the surface of Mars and a forebody deploys from the

probe. The forebody is attached to the aftbody via wires. The forebody can penetrate up to about 2 meters. The aftbody contains a small UHF antenna. Future probes similar to DS-2 can survive long periods on the surface via solar arrays and/or small Radioisotope Heater Units (RHUs). Small probes enable network missions and missions too risky for large landers.

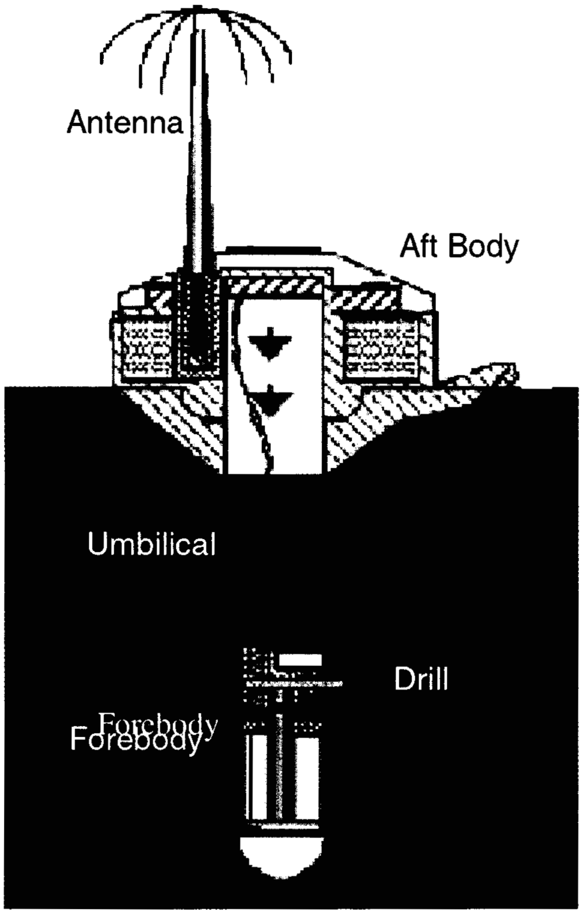

Figure 3 shows the deployed DS-2 probe. Future probes like DS-2 enable focused network science at Mars.

The in-situ communications system for a small probe is a challenge. Currently, JPL and Cincinnati Electronics are investigating an advanced radio communications UHF system. This system should be available for a 2005, or possibly the 2003, micromission. The near-term goal of this technology is a communications system that is less than 1 kg and requires less than 5 W Rf power.

Atmospheric Flight

A Mars Airplane flight is planned as a micromission in 2003 or 2005. This technology allows reconnaissance of large regions of the surface over short periods of time. Typical ranges are 200-400 km and flight time is about 15 minutes.

Another promising technology is balloon flight. Solar Montgolfiere balloons inflate via solar energy as they descend through the atmosphere at arrival. Then, this type of balloon stays aloft for one Mars day. More complicated, but more capable balloon technology includes super pressure balloons that can stay aloft days or weeks. These types of balloons can cover hundreds to thousands of km during the balloon. A large advantage of airplanes and balloons over orbital reconnaissance is the proximity to the surface. Many science investigations require sufficient signal to noise only provided by being within tens of km's of the surface.

Soft landers and rovers

Soft landers enable delicate scientific instruments such as seismometers access to the surface. With micromissions, it is conceivable to land several kg on the surface. Solar arrays can then provide energy for missions of several days to several hundred days, depending upon the Martian season of landing.

Rovers, like the MUSES-CN rover (see figure 4), could be soft landed via balloons on the Martian surface. Until now, rovers needed a lander to relay data back to the Earth or a Mars orbiter via UHF. The MarsNet network low altitude comm/nav orbiters with low power in-situ UHF data relay capabilities will allow rovers to land and relay their own communications independent of a lander. Small rovers could be sent to risky locations identified via orbital reconnaissance.

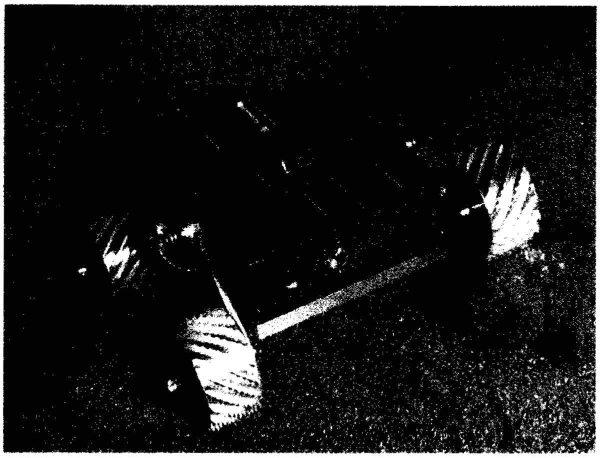

Figure 4 shows a demonstration of a microrover. Rovers such as this could be soft landed on the surface of Mars via micromissions and function independently without a lander.

Science Orbiters

Micromissions can go into orbit around Mars and carry a small payload (see figure 5). The current science orbiter payload mass is 6 kg. Small, focused science is possible within this mass.

The current requirement for micromission pointing is 1°. Most nadir pointing imaging needs better pointing than this. 0.1° is adequate for most imaging science. The science orbiter can use reaction wheels to achieve this pointing. Or, a new technology minimum impulse bit thruster could provide the improved pointing requirement with no added propellant.

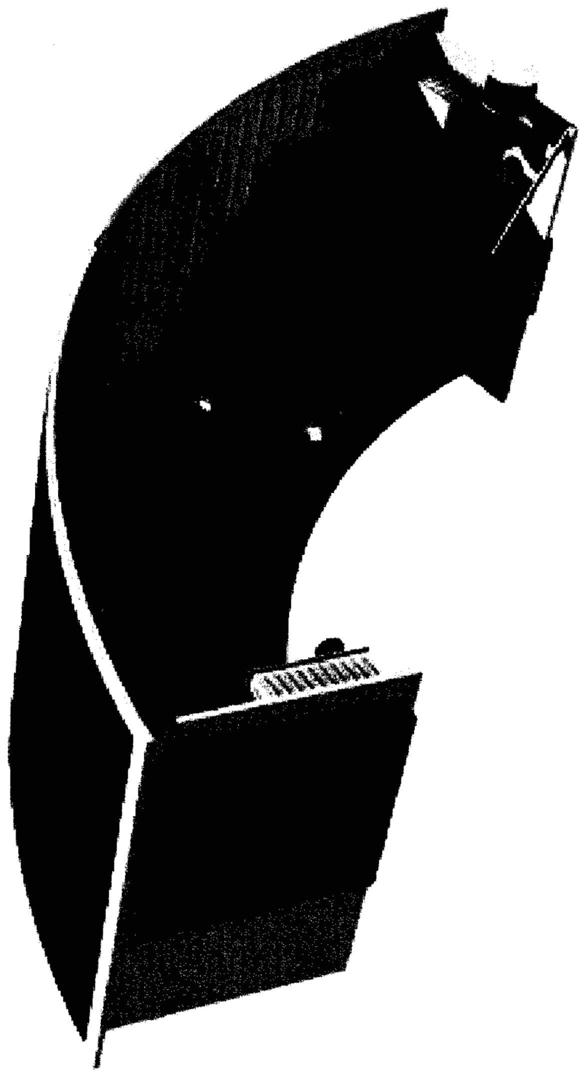

Figure 5 shows the science orbiter micromission without payload. The payload can go in the center region between the gold-domed propellant tanks. Large view zones with nadir pointing are possible. Sun pointing is also possible by a small aperture through the solar array curved structure (blue curved surface). A medium or high gain antenna is necessary to relay data back to Earth and is not shown here.

IV. Micromission spacecraft technologies

Micromissions could use several technologies should they become available in the future. Since micromissions are mass and volume constrained, technologies which decrease mass or volume are of particular interest. Figure 6 shows the strange "banana" shape of a micromission probe carrier. This shape is due to the ASAP5 form factor of 80° of a 360° secondary payload adapter. The available volume is approximately 800 mm high and 600 mm wide following an arc of 80° with the outside of the arc following the 5 m diameter payload fairing of the Ariane 5. Two standard ASAP5 spacecraft interface points ("twin") underneath the gold-domed propellant tanks provide the launch vehicle attachment.

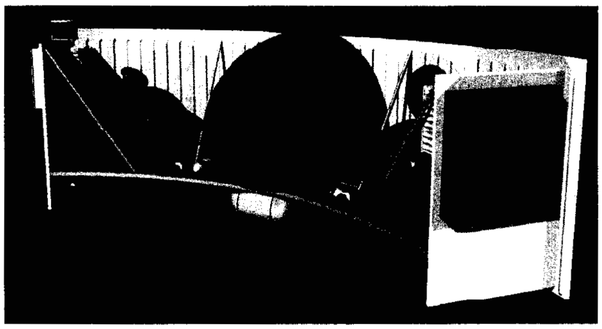

Figure 6 shows the unusual "banana" shape of a micromission probe carrier in artist's concept. The circular brown shape in the middle is the probe. The gold domed objects are the propellant tanks. Probe carriers can carry 1, 2, 4, or 6 probes in the future. For a micromission orbiter, the probe mass, except for 6 kg, becomes additional propellant mass in the larger propellant tanks. Additional propellant accomplishes Mars Orbit Insertion and aerobraking

To enable future increases in payload mass, several key technologies are identified that reduce micromission spacecraft bus dry mass.

- lightweight bi-propellant propulsion components
- lightweight telecommunications equipment
- advanced, lightweight batteries
- high power, low mass solar arrays
- ballutes for aerocapture or landing
- advanced phased array antennas that incorporate solar cells

Bi-propellant propulsion components

The 2003 micromission launch mass is 222 kg. Of this 222 kg, 73 kg is the dry spacecraft mass for a comm/nav Mars orbiter. This leaves 135 kg of usable propellant, 2 kg of scar mass for the launch vehicle adapters, 6 kg of propellant ullage, and 6 kg for the UHF in-situ communications payload.

Current work at JPL has the potential of reducing the propellant tank mass by 5 kg by using new PBO wrapped tanks with thin titanium walls. Another 5 kg of dry mass is potentially saved by reducing the valve and filter mass which is currently based on Cassini technology. Saving 10 kg in propulsion system dry mass enables a 2005 comm/nav orbiter that requires 10 kg more propellant to achieve the 300 m/s extra ΔV above the 2003 opportunity (see Table 1).

Advanced lightweight batteries

Lithium ion batteries have the potential to save 4 kg of dry mass in the power system. Current technology development for lithium ion batteries for Mars rovers and landers is leveraged to provide mass savings for the micromission orbiter missions.

High power, low mass solar arrays

Current solar array state of the art is triple junction gallium arsenide (GaAs) solar cells. Improvements in efficiency of the solar cells and increases in the power per unit solar cell area benefit micromissions. A decrease of one kg in the solar array mass allows one kg more of payload.

Ballutes for aerocapture or landing

A ballute is a cross between a balloon and a parachute. A ballute greatly increases the area during an atmospheric passage. Increased area provides an increase in drag. A ballute allows the micromission orbiter to make a high-altitude passage through the Mars' atmosphere. During this passage and after achieving the desired decrease in ΔV, the ballute is detached from the micromission spacecraft. The spacecraft then proceeds directly into a circular orbit after raising periapsis at apoapsis of the post-ballute aerocapture orbit (see Figure 7).

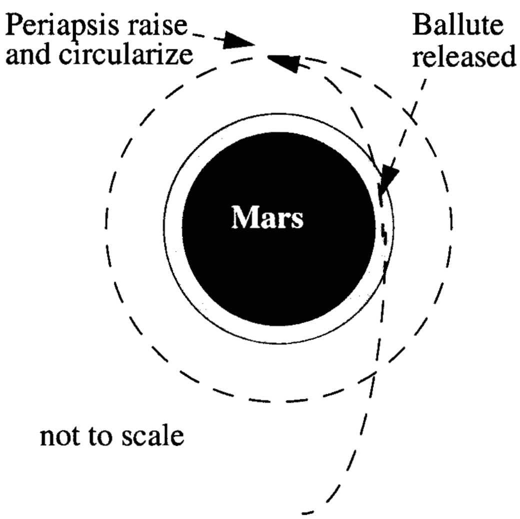

Figure 7 shows the sequence of events during a micromission ballute aerocapture.

The ballute aerocapture provides several advantages over traditional thermal protection system aerocapture. 1) A ballute is low mass compared to a thermal protection system. The micromission orbiter for 2005 could use as little as 15 kg for the ballute system. 2) Ballute aerocapture provides an operational orbit months before any micromission aerobraking scenario. 3) Ballutes can possibly also be used in future missions for entry and then utilized as balloons after descent. This will allow considerable savings over separate entry and descent systems with a balloon payload.

The heating experienced by a ballute is minimized due to the relatively high passage through the atmosphere. A typical atmosphere passage goes no lower than 80 km altitude. Current materials can easily endure the maximum predicted temperature of around 300° C. Much work still needs to be done to prove the concept. But, a ballute for the 2005 micromission is an attractive option. An Earth atmosphere flight test would enhance the chances or flying a Mars ballute. The ballute concept can also be used at any planet or satellite with an atmosphere.

Figure 8 shows an artist's concept of a micromission orbiter ballute. A ballute could fly as early as 2005 on a micromission. The 2005 opportunity is challenging from a ΔV standpoint. Ballutes are useful for missions like the 2005 Mars orbiter opportunity where the arrival velocity is high. Ballutes are the best solution if the launch energy is relatively low and the arrival velocity is high. If the situation is reversed and the launch energy is high and the arrival velocity is low, a ballute does not make sense since the launch mass must be kept low. In this case, propulsive capture is the best solution. The 2003 opportunity is such a case.

Ballutes also enhance the effectiveness of micromission comm/nav orbiters. A ballute delivered orbiter can be ready to support communications relay links from circular orbit within one week of ballute aerocapture. Aerocapture orbiters require about 4 months to get into a circular orbit from the highly elliptical capture orbit. Aerocapture comm/nav orbiters have a difficult time supporting missions at Mars until reaching the final operational circular orbit. This means that the best scenario for aerocapture comm/nav orbiters is to send the orbiter mission to Mars one Mars opportunity before necessary (about 26 months). This shortens the useful life of the mission since the comm/nav orbiter must wait in Mars' orbit for a long period of time while not supporting other Mars missions.

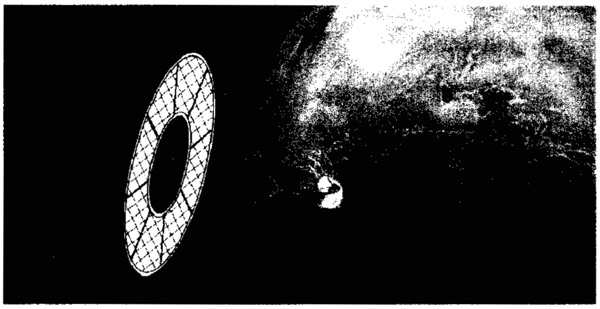

Figure 8 shows an artist's concept of a lenticular ballute during the beginning of the Mars' atmospheric passage. When the desired ΔV is achieved via ballute drag, the ballute tether is cut. Then the micromission orbiter is captured with one high atmospheric passage.

Advanced phased array antennas

Further mass savings are realized if the solar array can also function as an antenna. Several ground demonstrations have shown this to be possible. In the 2007 time frame, this technology could be available. About 2 kg for a high gain antenna could be saved while providing enhanced mission data return. This 2 kg can be turned into payload mass.

VI. Conclusions

Mars micromissions provide low cost access to Mars. Focused science missions and telecomm/navigation orbiter networks benefit from the small and simple secondary payload Mars micromissions. Many technologies can improve the science investigations and enable missions too expensive to fly in the past. Micromissions have a path utilizing low mass, power, and volume technologies to reduce mass and increase capabilities while holding mission cost low. This path will enable missions that are only dreamed about today.